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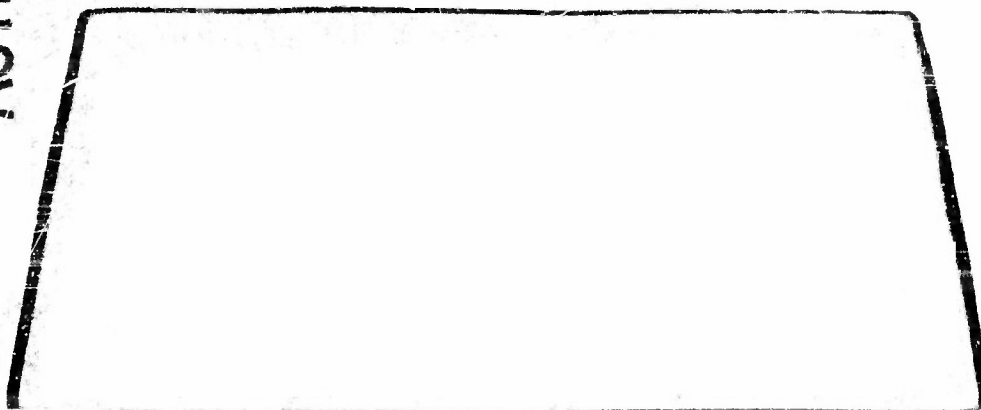
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Interaction of Fast Atoms and Ions

with Metal Surfaces

January ~~September~~ 1, 1954 3

Introduction

In the period since the last report, the measurement of the fraction of the ions reflected unneutralized from a metal surface has been continued. Previously, a number of different ion collecting arrangements had been tried but in all cases a secondary effect prevented the realization of an accurate measure of the reflected ions. The most troublesome of these secondary effects has been the removal of electrons from the collector by the bombarding ions and neutral atoms. To reduce this a grid shielded collector has been used with as satisfactory results as probably can be obtained in view of the extremely small fraction of the ions that are reflected.

Measurements of the average energy of the reflected particles have been continued. But as yet no unambiguous method of treating the data has been developed. For, the lack of charge of these "now neutralized" ions makes the measurements of their energy and equivalent current difficult. However, order of magnitude results can be obtained.

This report will discuss the modifications which have been made in the collector to decrease the relative size of secondary effects, the analysis of the data to determine an upper limit to the reflected ion current, an indirect method of measuring the equivalent current of a neutral atom beam and an estimation of the average energy of the reflected particles. The projected work for the next several months will be briefly described.

Apparatus Modifications

The collector-target assembly is the same as shown in figure 1 of the September, 1952 report. The collector, itself however, has been changed to reduce the secondary electron current induced by ion and neutral atom bombardment. Previously this consisted of a set of louvers

in a rectangular box covered with a copper mesh. All of these parts were electrically connected and constituted the collector. This has been modified by replacing the louvers by a plane copper sheet insulated from the shielding box and from a set of grid wires that replace the copper mesh. The grid wires are placed parallel to the plane of incidence of the ions. Earlier measurements on the energy of the secondary electrons removed from the collector showed them to have energies generally less than 4 ev. Consequently, the grid to collector voltage was to be such that electrons of this upper energy would be returned to the copper sheet now the collector proper. Further, as few as possible secondary electrons removed from the grid should be drawn to the more positive collector. To determine the maximum spacing of grid wires possible such that the above conditions are met several models on electrographic paper were tried. The arrangement shown in figure 1 was chosen for the experiment. A continuous equipotential of 4 ev. insures return of the electrons to the collector with potentials of 0 v. on the collector, -5.3V on the grid and +10.4V on the target with target to grid spacing of $1/2$ ", grid-collector separation of $1/4$ " and 5 mil grid wires $3/32$ " apart. Voltages as above or in the same ratio were used throughout the following experiments.

The targets used were ribbons 1 or 2 mils thick, $1/8$ " wide which could be directly heated by the passage of a 60 cycle alternating current. The voltage drop along this ribbon was less than $1/2$ volt and the D.C. potential of the target was applied to a bridge such that the point of the ribbon under bombardment was held fixed.

Reflected Ions

With the apparatus described above, it was possible to measure the ion current reflected from the target into an angular range of 0° to 70° in the plane of incidence on the side of specular reflection. Ion beams of He^+ and A^+ with energies from 500 ev to 2000 ev were used to bombard targets of Pt, Ta, W, Re and Ni. Measurements were made after the targets had been degassed several days at temperatures from 1000 - 1600°K depending on the melting point of the metal. Also the target was kept as hot as was compatible with a low positive ion emission during the measurements. For comparison some data was taken on targets at less than 500°C and at room temperature after flashing.

In practically all measurements with the target positive, with a magnetic field several hundred gauss to prevent electrons from reaching the collector, and with the grid negative to prevent loss of electrons from the collector, a small negative current to the collector was measured. This was assumed to be electrons removed from the grid wires under bombardment of the reflected particles. For a few of the targets after standing at reduced temperature a small positive current was found but this always disappeared on heating the target. It, of course, is possible that a reflected positive ion current exists but is masked by the electrons from the grid. To test this and to see if the small positive currents sometimes obtained were truly reflected ion currents and not ionized occluded gas molecules, a comparison of effects under ion bombardment and similar energy neutral atom bombardment were made.

Under neutral atom bombardment a small negative current to the collector is also obtained with same voltage arrangement as above. If the grid is made more positive than the collector, any electrons

released from the collector, may escape. This can be used as a relative indication of the neutral atom beam size. To obtain an absolute value for the neutral beam, it may be compared with the ion beam. For if all of the ions on approaching the metal surface are neutralized to the ground state before any real collision with the metal then these, too, should be reflected with the same energy losses and with the same angular distribution as the neutral atom beam. Therefore on reflection these particles will release electrons from the collector when the grid is positive. And the ratio R of collector currents when holding electrons (negative grid) to that when releasing electrons (positive grid) should be the same for both incident neutral atom and ion beams. Since the ion beam may be measured by the current to the target, we have an indirect method of measurement of the neutral beam size. This has been used in determining the secondary electron coefficient (electrons released per particle) for the neutral atoms. Even if the reflected particles under ion bombardment are not in the ground state the ratio should be the same if the electron removed from the grid wires (copper) and the collector (copper) are of equal efficiency. This would not be true for different angular distributions of the reflected particles.

Assuming equal values of R it is possible to calculate the collector current when holding electrons with ions incident on the target. Comparison of this with the measured should give an indication whether there is any true reflected ion current which would be the case if the calculated current were a larger negative value than the measured. The difference divided by the incoming ion current gives the fraction reflected into the angular range of the collector, which is roughly $1/2$ of the hemisphere.

The use of the above method of comparison of the neutral and ion reflected particles seems to be the only way of arriving at anything like a definite result. This is because of the smallness (if not zero) of the fraction of ions reflected and of the presence of ionized adsorbed molecules removed under bombardment. In table I, there is a series of values found as above for the fraction of ion current reflected for various targets and ion beam energies. Since the calculation involves a small difference of the order of the error in the quantities, it is to be expected that the results are meaningful in magnitude only. This is probably the cause of the negative values of the fraction reflected.

Experiments with N_1 as the target were inconsistent and so are not included in the table. This might be caused by oxidation of the target under heating to outgas it. On removal, the N_1 target had a rough, greyish-black, dull appearance unlike that of a clean metal surface.

Average Energy of Reflected Particles:

By measuring the emitted electron current produced by bombardment of the collector by the reflected particles we have a rough measure of the average energy of these particles.

For let $\int f(E)dE$ = number of reflected particles striking the collector/sec. with energy in the range dE at E .

and if $\tau_0(E)$ = number of electrons removed by a neutral particle of energy E

then $\int_0^{E_0} \tau_0(E) f(E)dE = N_e$ = number of secondary electrons removed/second from the collector. $\tau_0(E)$ can be measured by bombarding an undegassed target of material like that of the collector with a neutral beam of known energy. The size of the neutral beam can be measured as described above by comparing its reflected particles

with those of an ion beam.

Since $f(E)$ is not known, we can obtain only a weighted average value for E .

$$\text{Let } \bar{\sigma}_0 = \frac{1}{N} \int \sigma(E) f(E) dE = \frac{\sum \sigma_i}{N}$$

where $\bar{\sigma}$ represents an average value of the quantity σ defined as above, and N is the number of particles striking the collector/sec ($= \int f(E) dE$). Previous measurements have indicated that N is about 50% of the number of incident on the target. Or more correctly, the secondary electron current from the collector on the specular reflection side is about the same as that from the collector shield and the opposite side of the collector plane. Assuming that all incident particles are reflected, we have a rough estimate for N .

Values of $\sigma_0(E)$ for H_e and A on undegassed brass target were measured and are shown in table II. Values of $\bar{\sigma}$ for several cases H_e^+ on Pt and A^+ on Pt were calculated and the values of the energy for which $\bar{\sigma} = \sigma(E)$ are shown in table III.

Summary:

The following tentative conclusions may be drawn from the results described above:

(a) The neutralization of the rare gas ions H_e^+ and A^+ on such metals as Pt, W, Ta, and Rh is essentially 100% for an angle of incidence of about 30° . A small fraction ($\sim .1\%$) which might be reflected unneutralized cannot be definitely determined because of various background effects. Any dependence of this efficiency of neutralization on velocity of the ions or temperature of the metal surface cannot be observed under the present conditions.

(b) As a consequence of (a) the efficiency of neutralization of He^+ and A^+ on these various metals is not dependent on the relative positions of the stationary electron states in the impinging atoms and the Fermi level of the metal. See the August, 1952 report for a diagram of these states. It may be that the efficiency of neutralization is so high that even for atomic levels lying above the Fermi level the process is essentially certain even with the much smaller number of electrons of energy suitable for the transition. (See Cobas and Lamb, 1944.)

(c) While it seems that helium atoms retain considerably more of their energy on reflection than argon, these measurements are not complete enough for an unambiguous interpretation. It might be that the helium is reflected as a metastable atom which would increase the electron emission from the cathode over that of a ground state neutral of the same kinetic energy. Thus the particles would appear more energetic. Also there is no method other than a rough estimation of determining the number of reflected particles.

Work in Progress:

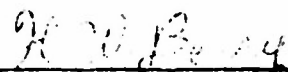
Two lines of attack will be continued. One will be the examination of the efficiency of neutralization for grazing angles of incidence of the positive ions. Using ions of several hundred ev and angles of several degrees normal velocities equivalent to about 7 ev can be obtained. Consequently, distances of closest approach of ion and metal atom will be larger and perhaps a lower neutralization will occur. A schematic diagram of the apparatus for this is shown in figure 2. A second problem will continue in part the examination of the energies of the reflected and neutralized ions for a 30° angle of incidence. Apparatus containing a moving collector is almost complete.

With this the angular distribution of the reflected atoms and the secondary electrons removed from the target may be measured. If possible, an attempt will be made to distinguish between reflected metastable and ground state atoms.

References:

Cobas & Lamb, Physical Review, Vol. 65 page 327, 1944 (See footnote on page 337).

Signed-



H. W. Berry

Personnel:

H. W. Berry
R. E. Abbott

TABLE I

Ions Reflected (percent)

Voltage \ Ion	He ⁺ on Pt	He ⁺ on W	He ⁺ on Ta	He ⁺ on Rh	A ⁺ on Pt	A ⁺ on W	A ⁺ on Ta	A ⁺ on Rh
500		-.04	.01		0	.01	750 ev .02	-.01
1000	-.08	.04	-.03	-.02	0	.03	.02	.02
1500	-.28	.05	0	.04	.01	-.01	.05	0
2000	-.19	-.14	.03	0	0	-.01	.03	.04

TABLE II

Electrons removed from undegassed brass per incident neutral atom.

Energy (ev) \ Ion	300	500	750	1000	1500	2000
He on Brass	0.22	0.50	0.61	0.85	1.1	1.46
A on Brass	0.35	0.49	0.61	0.75	0.96	1.24

TABLE III

Average energy in ev of reflected neutral atoms.

Incident Ion \ Energy	500	1000	1500	2000 ev
A ⁺ on Pt	negligible	50		100
He ⁺ on Pt	100	400	700	700

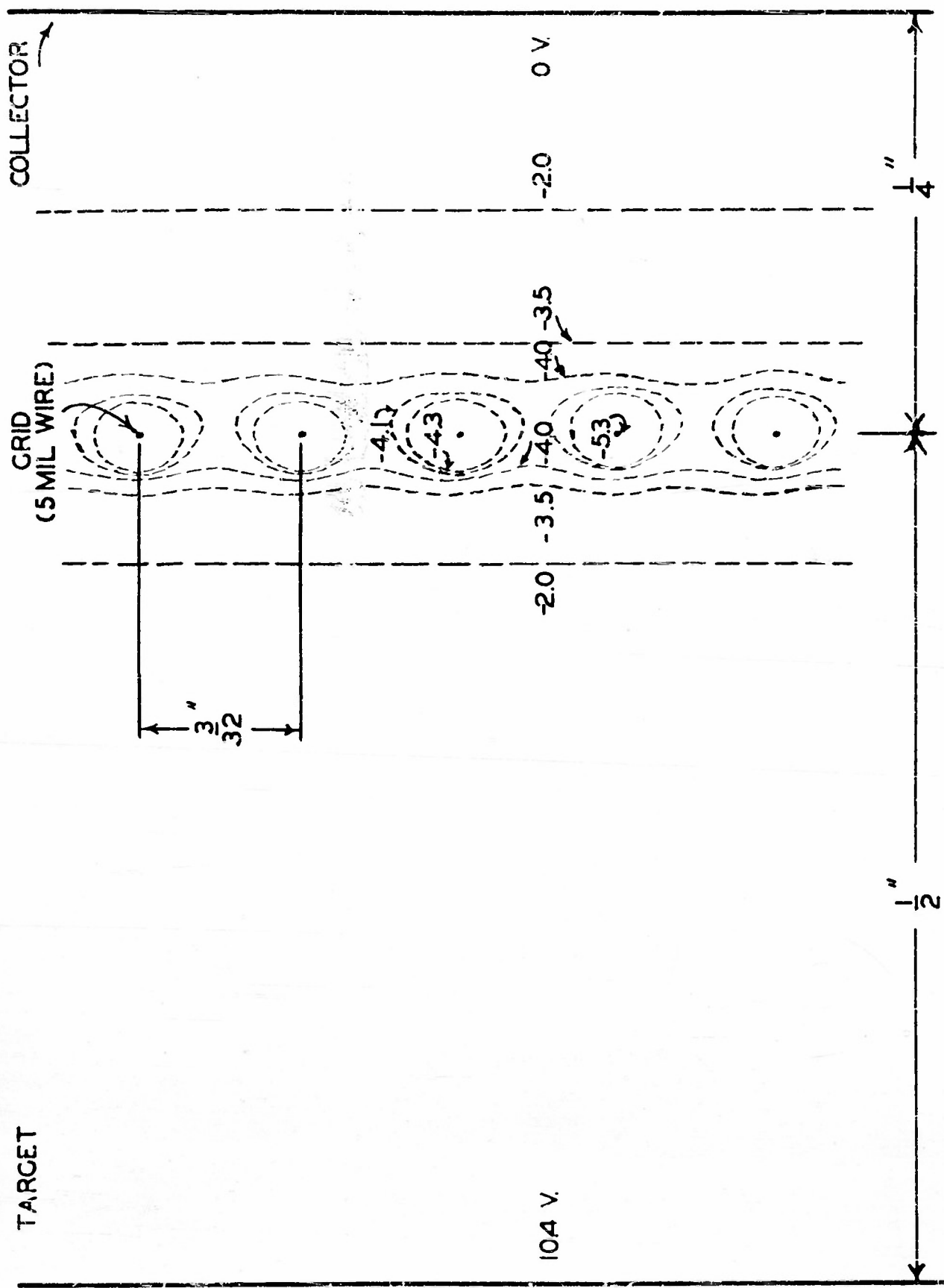


FIG. 1 SEC. ELECTRON RETARDING FIELD

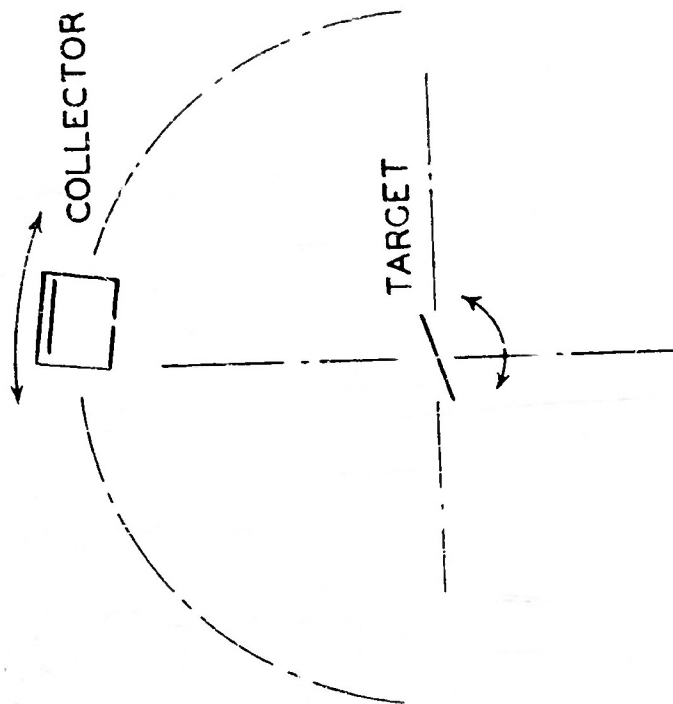
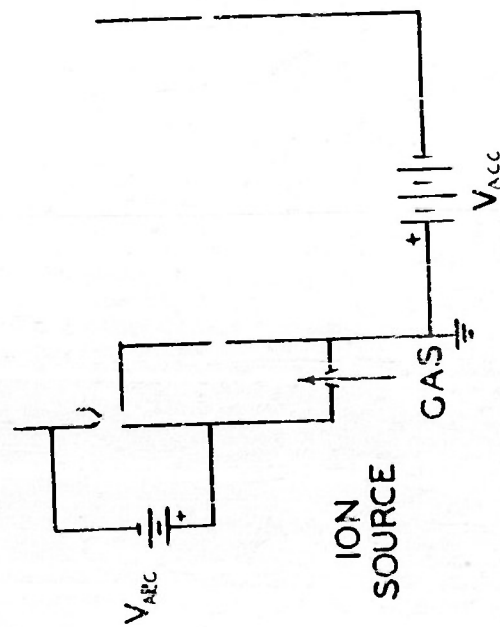


FIG. 2
EFFICIENCY OF NEUTRALIZATION
AT GLANCING ANGLES

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